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PERFORMANCE EVALUATION OF THE SELF-CONTAINED TOXIC ENVIRONMENT PROTECTIVE OUTFIT - INTERIM (STEPO-I) SYSTEM

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A quantitative protection factor (PF) evaluation was conducted on the Interim Self-Contained Toxic Environment Protective Outfit (STEPO-I). The STEPO-I is a protective ensemble consisting of a fully encapsulating suit with two alternative breathing and cooling systems. The suit is made of an impermeable, butyl rubber-coated nylon. The respirators consist of a closed-circuit breathing apparatus and a tethered airline emergency breathing apparatus. The closed-circuit breathing apparatus is worn with a battery-powered ice vest to provide cooling. The tethered air line emergency breathing apparatus vents a portion of the airline pressure to the wearers' extremities for blown-air cooling. Quantitative PF testing was conducted on each of the respirators and on the suit. Protection factor testing of the breathing apparatuses was conducted without the encapsulating suit to ensure a uniform challenge atmosphere. Both respirators performed very well due to their positive pressure. The suit was tested while worn over each of the respirators. The results showed that the vented air in the tethered airline mode provided a high degree of protection inside the suit. However, the closed circuit breathing apparatus does not vent off much air, and it was discovered that a significant flow of the challenge aerosol was entering the suit while in this mode.

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PREFACE

The work described in this report was authorized under Project No. 1S463747D669 and Sales Order No. GOGX, STEPO-I. This work was started in March 1990 and completed in June 1990.

The research described in this report was conducted under the review of the U.S. Army Edgewood Research, Development and Engineering Center (ERDEC), formerly the U.S. Army Chemical Research, Development and Engineering Center (CRDEC), Human Use Committee. This work was conducted under the Type Protocol for the "CRDEC Respirator Quantitative Fit Testing Program," Log No. 4448, 8 April 1989. The specific Human Use Protocol for this study is entitled "Simulant Aerosol Challenge Testing of the Self-Contained Toxic Environment Protective Outfit - Interim (STEPO-I) System," Log No. 5135, 12 July 1989.

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PERFORMANCE EVALUATION OF THE SELF-CONTAINED TOXIC ENVIRONMENT PROTECTIVE OUTFIT - INTERIM (STEPO-I) SYSTEM

1.0 BACKGROUND

The Army safety community has long recognized the need for an improved chemical protective ensemble to replace the M3 Toxicological Agent Protective (TAP) Suit. A Statement of Need - Clothing and Individual Equipment (SN-CIE) was approved for a 4-hour protective ensemble in January 1987. The U.S. Army Natick Research, Development and Engineering Center was tasked to plan and execute the Self-Contained Toxic Environment Protective Outfit (STEPO) development program. In early 1987, the STEPO program was accelerated under direction of the U.S. Army Vice Chief of Staff and subsequently divided into two distinct efforts, an interim program (STEPO-I) and a long-term program (STEPO). The interim program is the accelerated effort to develop a protective ensemble to provide total respiratory and skin protection for depot workers storing and maintaining chemical munitions in highly toxic and/or oxygen deficient environments. The STEPO-I is designed to provide a 2-hour breathing and cooling capability to the user.

2.0 INTRODUCTION

The STEPO-I system is a totally self-contained chemical protective ensemble which employs two alternate types of respirator systems. The ensemble consists of a fully-encapsulating butyl-rubber overgarment (referred sometimes herein as the "suit") which is worn with either a closed-circuit breathing apparatus (CCBA) and cooling vest or a tethered airline emergency breathing apparatus (EBA). Both breathing apparatuses are equipped with a full-facepiece mask with nosecup. Butyl-rubber M3 TAP gloves and boots are also worn with the ensemble.

The CCBA is a positive-pressure, 4-hour respirator system which simultaneously supplies oxygen to the breathing air while removing respired carbon dioxide. Oxygen is supplied at a rate of 1 lpm by means of a regulated high pressure gas cylinder. Carbon dioxide is removed by passing the breathing air through a bed of carbon dioxide absorbent. The recirculated air passes through a cylinder containing frozen "blue ice" which moderates the temperature of the breathing air. The complete CCBA weighs approximately 39 pounds. An independent ice-water cooling vest provides body cooling to the wearer.

The EBA uses a high pressure airline tether to supply breathing air to the user. In the event that the air supply is lost or the user is forced to disconnect, the EBA has a back-up cylinder of breathing air which will last for approximately eight minutes. This is designed to give the user time to safely exit the contaminated area and doff his

protective equipment. The EBA supplies its own means of cooling. A portion of the high pressure air from the airline is vented to an array of flexible plastic tubes. These tubes are strapped to each of the user's arms and legs where air is exhausted through the perforated ends to provide cooling. A fifth tube exhausts air around the mask visor for cooling of the head. All of the supplied air passes through an in-line carbon cartridge for the removal of chemical contaminants.

3.0 OBJECTIVES

The purpose of this test was twofold. The first objective was to measure the protection factor (PF) performance of the two STEPO-I breathing apparatuses. The second objective was to measure the PF performance of the STEPO-I protective garment. In this report, the term "protection factor" is used to describe the overall protection afforded by the respirator system or protective garment when worn in a simulated operational (i.e., a laboratory) setting.

4.0 TEST SUBJECTS

Twenty-four (24) male subjects were recruited from the 143rd Ordnance Battalion located at Aberdeen Proving Ground, MD for Phase I evaluation of the breathing apparatuses. Five (5) male subjects were recruited from Pine Bluff Arsenal for Phase II evaluation of the STEPO-I protective overgarment. All volunteers were thoroughly briefed on the nature and purpose of the study and informed consent was obtained from each volunteer upon completion of a volunteer agreement affidavit.

5.0 METHODS AND PROCEDURES

5.1 Corn Oil Aerosol Test Method

A 10 ft by 10 ft by 32 ft test chamber was used for this study. A polydispersed aerosol challenge is generated by atomizing liquid corn oil using an array of Laskin nozzle nebulizers. The Laskin nozzle generates a coarse aerosol mist by using low pressure filtered air to shear off particles of corn oil. The resulting airflow being generated by the nozzle carries the mist upwards into a separate chamber of the nebulizer where the airstream is deflected by a calibrated impactor plate to remove the larger particles. This produces an aerosol consisting of the desired particle size range. A uniform challenge concentration of approximately 25 mg/m^3, having a mass median aerodynamic diameter (MMAD) of 0.5 - 0.6 micrometers, is maintained within the test chamber through controlled dilution with room air by a 300 cfm filter/blower system.

A computer automated forward-light-scattering photometer system is used to quantify the amount of aerosol leakage within the protective mask or suit (1). The photometer measures the amount of light scattered by the aerosol in the sample stream

and converts it to a voltage. The output is digitized and processed by the microcomputer system. The photometer unit used in the test system responds to a five-decade range in aerosol concentration. At the beginning of a test, the photometer is automatically adjusted to full scale (100%) to measure the chamber concentration. Both the initial chamber and subsequent in-mask or in-suit concentrations are determined by integration. In-mask and in-suit concentrations are measured as a percentage of the chamber concentration. The ratio of the outside challenge concentration to the concentration measured inside the mask or suit is defined as a mask/suit PF. The protection factor, therefore, represents a quantitative measure of the performance of the protective equipment. The larger the value, the greater the protection provided by the protective equipment. The photometer system has an upper sensitivity limit of .005% and is thus capable of measuring PFs up to 20,000.

At the conclusion of a test trial, the computer calculates an overall (average) PF by taking the inverse of the arithmetic mean of the individual exercise penetration values measured during the course of the test. In addition, exercise PF values are computed from the inverse of the individual exercise penetration values. The overall PF values along with the individual exercise PF values are stored on a computer diskette for subsequent analysis.

5.2 Test Procedure

The PF testing was divided into two phases. Phase I consisted of testing the two breathing apparatuses without the use of the protective suit. Phase II evaluated the protective suits while being worn with each breathing apparatus.

Prior to testing, volunteers were instructed and assisted by CRDEC test personnel in donning the specific protective equipment to be evaluated. The air inside the protective equipment was continuously sampled at a rate of 1 liter per minute through a single 10-foot length of flexible silicone tubing connecting the sample probe(s) to the photometer detector unit.

In Phase I, a single probe was inserted in the facepieces of each respirator system. The MSA EBA facepiece probe was positioned in the upper center of the visor between the wearer's eyes. The Biomarine facepiece was probed in the nosecup. The probe was inserted into the nosecup through the rubber faceblank at a point directly below and to the right of the visor. This sample location was selected due to the inherent design of the facepiece. In closed-circuit breathing apparatus, such as the Biomarine unit, sampling from the eye region is prohibited since there is no free exchange of the breathing air between the oro-nasal area (nosecup) and eye cavity of the facepiece.

The volunteers were sized by the test personnel for fit in the EBA facepiece which comes in three sizes: small, medium and large. The Biomarine facepiece comes only in one size, medium. Two facial measurements were recorded for each individual; the face length or menton-nasal root depression distance and the face width or bizygomatic diameter. This data is presented in Table 1 below.

Table 1. Phase I: Subject Facial Anthropometric Data.

Subject No.	Face Length	Face Width	MSA EBA Facepiece Size
1	120 mm	143 mm	L
2	114 mm	136 mm	M
3	112 mm	137 mm	M
4	122 mm	143 mm	L
5	111 mm	142 mm	M
6	119 mm	137 mm	L
7	107 mm	141 mm	L
8	112 mm	137 mm	L
9	116 mm	134 mm	L
10	124 mm	136 mm	L
11	125 mm	138 mm	L
12	120 mm	135 mm	L
13	120 mm	137 mm	L
14	118 mm	147 mm	L
15	117 mm	127 mm	M
16	103 mm	132 mm	M
17	108 mm	139 mm	M
18	128 mm	144 mm	L
19	119 mm	130 mm	M
20	124 mm	141 mm	L
21	115 mm	137 mm	M
22	121 mm	134 mm	L
23	122 mm	137 mm	L
24	119 mm	125 mm	M

Four subjects were tested at a time, two wearing the CCBA and two wearing the EBA. Each subject was tested twice in each respirator apparatus yielding a total of 48 tests per system. The subjects performed the following ten exercises, each 1 minute in duration:

- Standing still (normal breathing)
- Deep breathing
- Head movement, side to side
- Head movement, up and down
- Talking (recite "Rainbow" passage)
- Move and stack boxes
- Reach for floor and ceiling
- Climb stairs
- Facial expressions
- Standing still (normal breathing)

The above exercise protocol was adopted from a similar routine used in a prior study at CRDEC to evaluate the PF performance of two candidate STEPO-I CCBAs (2). The set of exercises was designed to provide a variety of simulated "generic" use conditions to stress the faceseal of the respirators.

Five STEPO-I overgarments manufactured by LifeGuard, Guntersville, AL were used for the Phase II testing. Each suit was probed at four locations on the left side. The four sample sites were the hood, the upper arm, the abdomen and the thigh. In order to obtain a representative measurement of total in-suit concentration, these four sampling sites were joined to a single sample line which ran to an individual photometer detector unit. Phase II consisted of testing five volunteer test subjects from Pine Bluff Arsenal in the total ensemble. Experienced users were sought for this phase of the testing due to the complexity of the equipment and the degree of burden it places on the user. In addition to the two facial measurements, the volunteers' height, weight, chest and waist measurements were also recorded. These measurements along with the volunteer's equipment sizes are shown below in Tables 2 and 3.

Table 2. Phase II: Subject Anthropometric Measurements.

Subject	Face Length	Face Width	Height	Weight	Chest	Waist
1	105 mm	131 mm	66"	135 lbs	36"	29"
2	125 mm	139 mm	72"	176 lbs	40.5"	34"
3	120 mm	142 mm	72"	190 lbs	42.5"	35"
4	97 mm	130 mm	64"	128 lbs	34"	28"
5	115 mm	147 mm	69"	260 lbs	45.5"	44"

Table 3. Phase II: Equipment Sizes.

Subject	CCBA Facepiece	EBA Facepiece	Life-Guard Suit
1	M	M	S
2	M	L	M
3	M	L	M
4	M	S	S
5	M	L	L

Each subject was tested six times with the EBA and eight times with the CCBA yielding a total of 30 and 40 tests, respectively. Subjects were tested in groups of two and three. All suits being tested with the CCBA were purged with clean bottled breathing air immediately prior to the subjects entering the chamber. This was done to remove any potential exogenous aerosols which may have entered the suit during donning. The subjects performed the following ten 1-minute exercises for the suit evaluation:

- Standing still (normal breathing)
- Half squat up and down, swinging arms above head
- Crawl on hands and knees
- Move and stack boxes
- Head movement, side to side
- Head movement, up and down
- Reach for floor and ceiling

- Climb stairs
- Twist upper torso
- Standing still (normal breathing)

The above exercise protocol was chosen to provide a more vigorous and wider range of body movements than used in Phase I in order to sufficiently flex the various portions of the suit. It is based on a similar routine used in a previous study at CRDEC for PF testing of the M3 TAP ensemble (3).

6.0 DATA ANALYSIS

6.1 Protection factor Calculation Method

The protection provided by a respirator or overgarment against a challenge agent can be expressed as the ratio of the concentration measured inside the respirator facepiece (mask) or overgarment (suit) to the challenge concentration measured outside the protective equipment; this ratio is called the penetration. The reciprocal of this ratio is called the PF. Both terms are presented by the following equations:

$$P = \frac{C_{mask}}{C_{challenge}}$$

and

$$PF = \frac{C_{challenge}}{C_{mask}} = \frac{1}{P}$$

where P = Penetration

$C_{mask\ or\ suit}$ = average concentration of challenge agent inside the mask or suit (mg/m^3)

$C_{challenge}$ = average challenge concentration (mg/m^3)

PF = Protection factor

6.1.1 Average Leakage Concentration per Exercise

The results of a PF test are usually expressed by a graph showing the instantaneous ratio of the in-mask (or in-suit) and challenge concentrations in the form of Penetration or PF versus time. The duration of each of the exercises in this example is 60 seconds. Within one exercise, the computer collects data at the rate of two data points per second. Hence, the average penetration for one exercise can be expressed as:

$$P_{exercise} = \sum_{i=1}^{n} \frac{P_i}{n}$$

where n = the number of data points collected per one minute exercise (n = 120)

and P_i = the individual measured penetration data point

6.1.2 Overall Protection Factor

In the same way, the overall PF, which represents the PF over the duration of the test, is expressed as:

$$PF_{overall} = \left(\sum_{i=1}^{m} \frac{P_{exercise\ i}}{m} \right)^{-1}$$

where m = number of exercises in one complete test

6.2 Statistical Analysis

All overall PF data presented in this report were statistically analyzed using binomial proportions of percentage of success. Continuous methods of analysis could not be used due to the truncation of data at a PF of 20,000.

6.2.1 Phase I

The analysis of the two respirators was based on a total of 48 PF trials conducted on each system. The 1667 and 6667 PF levels reported in this phase of the study correspond to standard pass criteria levels established under the U.S. Joint Service Operational Requirements for testing of the M40 military mask system and

were derived from combat threat analyses of the chemical-biological battlefield environment (4).

6.2.2 Phase II

The analysis of the suits was based on a total of 40 PF trials conducted with the CCBA and 30 PF trials with the EBA. Since no criteria exist for required pass levels for percutaneous protection factor protection, an arbitrary set of protection levels was created to show the differences between the two respirator systems.

Additional statistical analysis was performed on PF data obtained from the suit worn with the CCBA to determine whether the size of the STEPO suit has a significant effect on penetration and to determine which exercise(s) result in the highest penetration. In this case the PF is the ratio of the ambient aerosol concentration to the concentration to which the skin is exposed, not the respiratory system. The concentration near the skin represents the combined concentration of the four sampling locations.

7.0 DISCUSSION OF RESULTS

7.1 Phase I

Protection factor data are summarized in Tables 4 and 5 where pass percentages are given for both the Biomarine CCBA and MSA EBA over a wide range of PF levels. Overall PFs calculated for each subject can be found in Appendix A. No significant differences are observed between the two respirator systems in terms of pass percentages over the 500 to 20,000 PF range. Both respirator systems were shown to provide excellent protection as demonstrated by their ability to obtain 100 percent pass rates at the 10,000 PF level.

Table 4. PF Pass Percentage Results for CCBA.

Overall PF	Pass Percentage	90% Confidence Interval for Specified Pass Percentage	
500	100%	94.0%	100%
1667	100%	94.0%	100%
3000	100%	94.0%	100%
5000	100%	94.0%	100%
6667	100%	94.0%	100%
10000	100%	94.0%	100%
20000	100%	94.0%	100%

Table 5. PF Pass Percentage Results for EBA.

Overall PF	Pass Percentage	90% Confidence Interval for Specified Pass Percentage	
500	100%	94.0%	100%
1667	100%	94.0%	100%
3000	100%	94.0%	100%
5000	100%	94.0%	100%
6667	100%	94.0%	100%
10000	100%	94.0%	100%
20000	90%	79.3%	95.8%

Several instances of negligible leakage were noted with the MSA EBA. The MSA facepiece does not appear to produce as good a face seal as the Biomarine facepiece. The Biomarine facepiece is composed of silicone rubber which due to its pliability is known for its ability to form an excellent airtight seal against the skin. The MSA facepiece, on the other hand, is a neoprene rubber which is inherently stiffer than silicone. Specifically, several subjects were observed to have a small gap between the facepiece and the skin around the temple region. However, the lack of an airtight seal was essentially compensated by the positive pressure air flow delivered to the facepiece. Any nominal contamination that entered the facepiece was rapidly flushed out with clean air.

7.2 Phase II

This part of the evaluation showed a marked difference in suit PF performance related to the two breathing apparatuses. Significant differences are observed between the two suit systems in terms of pass percentages over the PF range of 400 to 20,000. Over that PF range, the 90% confidence intervals in Tables 6 and 7 do not overlap. The suit with the MSA EBA resulted in significantly higher pass rates than the Biomarine CCBA suit.

The PF criteria levels given in Tables 6 and 7 were arbitrarily derived by multiplying the preceding level, starting with 50, by a factor of two. The analysis was based on a total of 30 and 40 PF test trials conducted on the EBA and CCBA test configurations, respectively. A detailed presentation of the data can be found in Appendix B.

Table 6. PF Pass Percentage Results for Suit with CCBA.
Database consists of forty trials.

Overall PF	Pass Percentage	90% Confidence Interval for Specified Pass Percentage	
50	100%	94.4%	100%
100	90.0%	78.7%	96.5%
200	85.0%	72.5%	93.2%
400	70.0%	56.0%	81.6%
800	50.0%	36.2%	63.8%
1600	37.5%	24.8%	51.6%
3200	27.5%	16.3%	41.3%
6400	17.5%	8.5%	30.4%
12800	10.0%	3.5%	21.3%
20000	5.0%	0.9%	14.9%

Table 7. PF Pass Percentage Results for Suit with EBA.
Database consists of thirty trials.

Overall PF	Pass Percentage	90% Confidence Interval for Specified Pass Percentage	
50	100%	90.6%	100%
100	100%	90.6%	100%
200	100%	90.6%	100%
400	100%	90.6%	100%
800	100%	90.6%	100%
1600	100%	90.6%	100%
3200	100%	90.6%	100%
6400	100%	90.6%	100%
12800	100%	90.6%	100%
20000	100%	90.6%	100%

No detectable leakage was observed with the EBA/suit configuration. This was the result of over-pressurization in the suit created by the approximately 5 cfm of air being continuously bled off for cooling (1 cfm per cooling line). The Biomarine CCBA, however, does not provide positive pressure to the suit since it is a closed-circuit device. Notable leakage occurred in this mode. Individual exercise PFs for the CCBA/suit configuration ranged from 27 to 20,000. As shown in Table 6, only half (50 percent) of the suit/CCBA trials achieved PFs of greater than 800.

Various histograms made on the CCBA/suit data indicate that distribution of the data appears the most normal when the suit PF data are transformed to Log penetration (P). Data, in terms of PF or P, does not fit the normal distribution. Although 14% of the PF data are truncated at 20,000, (see Appendix B) a judgement was made that treating the >20,000 data as exactly 20,000 will not excessively distort the conclusions. After the data were normalized by converting them to log P, one-way ANOVA statistical tests were performed.

A statistical analysis was then performed on this data to determine whether the type of test subject affects log P values for the small suit size. For the analysis, only "average" P data were used. (The "average" P is the inverse of the overall PF, as defined earlier.) A group of 8 log P values for subject No. 1 wearing small suit No. S1

was contrasted against 8 log P values for subject No. 4 wearing small suit No. S2. Suit No. S2 was presumed to be identical to No. S1. A two sample "t" hypothesis test indicates a significant difference in terms of log P between subjects No. 1 and 4 at 95% confidence. Likewise, subject No. 2 with medium suit No. M1 was contrasted against subject No. 3, who also wore a medium suit (No. M2). A significant difference in mean log P was also demonstrated by the hypothesis test.

It is not possible to rigorously prove differences in log P means between suit sizes small, medium and large because of incomplete cells in the test matrix and because the subject effect was demonstrated to be significant. However, a "what if" exercise was performed for information. If data for suits No. S1 and No. S2 are combined, data for suits No. M1 and No. M2 are combined, and if the subject effect does not create a problem, then the suit size effect can be tested by a one-way analysis of variance. The dependent variable is "average" log P and the single independent variable is suit size with 3 levels (small, medium and large.) At the 95% confidence level, the calculated F statistic of 1.86 is less than the table critical value of $F_{.05,2,37} = 3.2$. using log P values. This suggests that the suit size effect is not substantial and all the subjects were likely fitted with the proper size suits.

The effect of exercise number on suit aerosol leakage was also studied. In Figure 1, a scatterplot of percent penetration (PP) versus exercise number suggests that leakage increases during exercises 1 through 6, and then approximately levels out during exercises 7 through 10. A plot of mean PP versus exercise number shows the same trend as illustrated in Figure 2. It is hypothesized that between exercises 1 and 6, the rate of corn oil aerosol entering the suit is greater than that exiting the suit. After exercise number 6 (which is approximately 6 minutes of cumulative sampling), influent and effluent flows appear to approach a partial equilibrium state. In the view of the authors, it is likely that exercise 6 (move and stack boxes) permits one of the highest penetrations of the 10 exercises.

The exercise number variable represents a composite of two other variables; exercise type and cumulative aerosol challenge time. Because of this, the particular exercise type that causes the largest PP can not be clearly determined from the data. PP from one exercise type is believed to influence the PP of the next sequential exercise. Longer exercise times and/or not challenging the suits prior to a specific exercise would give more insight into the exercise type effect.

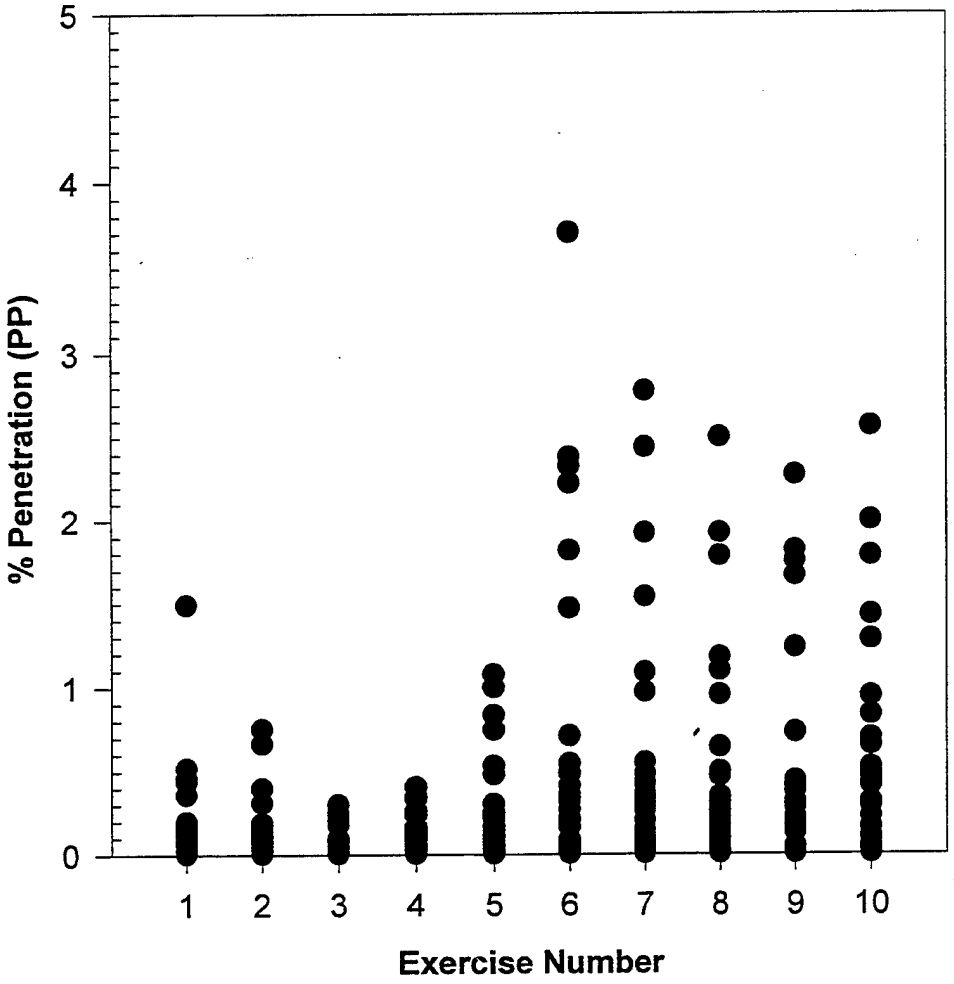

Figure 1. Scatterplot of percent penetration vs. exercise number for CCBA/suit configuration. Total of 400 data points.

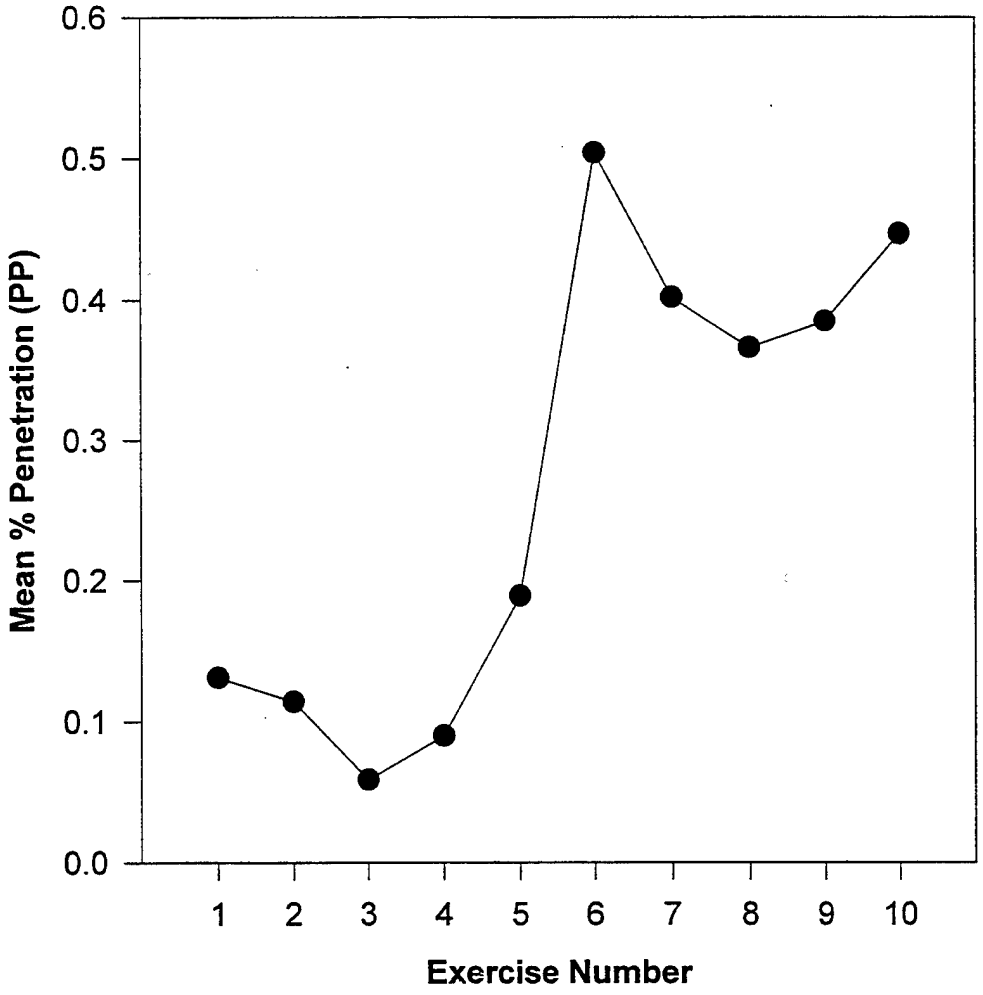

Figure 2. Plot of mean percent penetration vs. exercise number for CCBA/suit configuration.

8.0 CONCLUSIONS AND RECOMMENDATIONS

In Phase I testing, both STEPO-I breathing apparatuses achieved the high protection factor levels inherent to most positive-pressure respirator systems. These respirators offer excellent respiratory protection by maintaining a pressure above atmospheric in the facepiece during inhalation, thus preventing inward leakage of the contaminant.

The beneficial effect of positive-pressure was demonstrated in Phase II with respect to suit PF performance. The superior PF performance of the EBA/suit configuration can be attributed primarily to the positive pressure produced inside the suit by the EBA cooling air distribution system. Without this over-pressurization, outside air can enter the suit via the three exhaust ports located at the back of the hood, left side of the waist, and upper right arm of the suit. These exhaust ports consist of thin rubber flapper valves. The exhaust valves are used to reduce the volume of air within the suit which decreases the bulk, thereby increasing freedom of movement. However, since these values are passively activated, leakage can occur as a result of the flapper valves failing to open and close properly.

Subsequent informal testing was conducted using valve plugs which were supplied by the suit manufacturer, LifeGuard. These plugs consisted of a valve body from which the flapper valve had been removed and the opening closed off. The PF performance of the CCBA/suit configuration improved dramatically with the use of these plugs. These plugs are now in use with the fielded STEPO-I CCBA system.

A toxicological study should be conducted to determine the minimum PF that a suit wearer can tolerate during a four hour mission without harmful health effects.

LITERATURE CITED

1. Brletich, R.W., C.R. Allyson, and F.P. Hughes: *Development of an Automated System for Respirator Quantitative Fit Testing*, CRDEC-TR-88100, U.S. Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, May 1988, UNCLASSIFIED Report.

2. Gardner, P.D.: *M3 TAP Suit "Bellows Effect" Investigation*, CRDEC-TR-037, U.S. Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, March 1989, UNCLASSIFIED Report.

3. Kuhlmann, W.D., P.D. Gardner, R.G. Laye, and L.C. Moss: *Performance Evaluation of Two Closed-Circuit Breathing Apparatus for Use in Chemical Toxic Environments*, CRDEC-TR-062, U.S. Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, April 1989, UNCLASSIFIED Report.

4. Cited in Department of the Army, U.S. Army Training and Doctrine Command, Fort Monroe, VA, *Proposed 2nd Amendment to Revised JSOR for the M40 Protective Mask*, TRADOC, ACN 11954, 21 June 1985, UNCLASSIFIED Memorandum.

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APPENDIX A

Phase I: EBA and CCBA Protection Factor Data

Subject No.	Phase II Overall Protection Factors			
	Trial 1		Trial 2	
	EBA	CCBA	EBA	CCBA
1	20000	20000	20000	20000
2	20000	20000	20000	20000
3	10700	20000	20000	20000
4	20000	20000	20000	20000
5	20000	20000	20000	20000
6	20000	20000	16800	20000
7	20000	20000	20000	20000
8	20000	20000	20000	20000
9	20000	20000	20000	20000
10	20000	20000	20000	20000
11	20000	20000	20000	20000
12	20000	20000	20000	20000
13	20000	20000	19500	20000
14	20000	20000	20000	20000
15	20000	20000	20000	20000
16	20000	20000	20000	20000
17	20000	20000	20000	20000
18	20000	20000	20000	20000
19	20000	20000	20000	20000
20	20000	20000	20000	20000
21	19600	20000	19300	20000
22	20000	20000	20000	20000
23	20000	20000	19600	20000
24	20000	20000	20000	20000

APPENDIX B

Phase II: STEPO-I Suit Protection Factor Data

Phase II
Protection Factor of Suit with MSA EBA *

Subject No.:	1	2	3	4	5
Mask No.:	M2	L8	L5	S7	L4
Suit No.:	S1	M1	M2	S2	L1

EXERCISE	TRIAL					
	1	2	3	4	5	6
1	20000	20000	20000	20000	20000	20000
2	20000	20000	20000	20000	20000	20000
3	20000	20000	20000	20000	20000	20000
4	20000	20000	20000	20000	20000	20000
5	20000	20000	20000	20000	20000	20000
6	20000	20000	20000	20000	20000	20000
7	20000	20000	20000	20000	20000	20000
8	20000	20000	20000	20000	20000	20000
9	20000	20000	20000	20000	20000	20000
10	20000	20000	20000	20000	20000	20000
Overall PF	20000	20000	20000	20000	20000	20000

* No leakage of the suit was detected for any subject while in this mode. The results for all five subjects are condensed in this table. Total trials = 5 subjects x 6 trials/subject = 30 trials.

Phase II
Protection Factor of Suit with Biomarine Rebreather (CCBA)

Subject No.: 1
Mask No.: 1
Rebreather No.: P183
Suit No.: S1 (Trials 1-6)
S2 (Trials 7&8)

EXERCISE	TRIAL							
	1	2	3	4	5	6	7	8
1	277	699	230	621	1880	1312	20000	1224
2	321	870	251	1328	2985	1701	20000	862
3	488	1304	565	1969	4831	3175	20000	4505
4	704	2151	602	1543	3145	3559	18940	6211
5	855	2342	588	1704	1808	3300	6757	4831
6	625	1124	299	1114	592	3012	505	1147
7	1144	1818	309	1992	826	4082	877	1393
8	1080	2309	391	2252	862	4202	725	1637
9	343	781	245	2257	550	3610	633	2096
10	316	340	106	2128	610	4132	637	1086
Overall PF	479	968	277	1460	1060	2790	1250	1620

Phase II
Protection Factor of Suit with Biomarine Rebreather (CCBA)

Subject No.: 2
Mask No.: 2
Rebreather No.: P167
Suit No.: M1 (Trials 1-6)
M2 (Trials 7&8)

EXERCISE	TRIAL							
	1	2	3	4	5	6	7	8
1	20000	20000	20000	16690	20000	20000	763	893
2	20000	20000	11300	20000	20000	20000	614	714
3	20000	20000	20000	20000	20000	20000	2770	1009
4	20000	20000	20000	20000	20000	20000	654	420
5	20000	20000	20000	5556	20000	9346	208	120
6	20000	20000	12840	1608	7463	3534	45	55
7	20000	20000	15530	3731	8696	3861	103	52
8	20000	20000	15020	5464	10820	5988	105	52
9	20000	20000	15550	5780	6211	6410	137	55
10	20000	20000	13210	5376	2778	7299	205	39
Overall PF	20000	20000	15700	5490	8990	7640	158	87

Phase II
Protection Factor of Suit with Biomarine Rebreather (CCBA)

Subject No.: 3
Mask No.: 3
Rebreather No.: P186
Suit No.: M2 (Trials 1-6)
M1 (Trials 7&8)

EXERCISE	TRIAL							
	1	2	3	4	5	6	7	8
1	787	505	1672	67	193	544	4149	1425
2	524	645	1174	133	150	320	990	1534
3	1085	1284	3003	426	332	398	1183	2169
4	380	1185	1946	246	297	287	1033	2262
5	100	893	595	188	93	134	694	2024
6	43	184	207	68	27	42	493	1348
7	41	319	207	36	65	92	488	1276
8	56	325	319	40	85	91	500	288
9	57	265	315	44	81	60	448	241
10	70	192	153	50	78	56	439	242
Overall PF	88	372	377	69	85	101	663	624

Phase II
Protection Factor of Suit with Biomarine Rebreather (CCBA)

Subject No.: 4
Mask No.: 4
Rebreather No.: P161
Suit No.: S2 (Trials 1-6)
S1 (Trials 7&8)

EXERCISE	TRIAL							
	1	2	3	4	5	6	7	8
1	4425	6250	20000	216	20000	885	10000	1350
2	20000	6667	20000	571	20000	962	14640	3106
3	20000	11100	20000	1121	20000	2016	19490	5848
4	20000	12640	20000	1011	20000	2110	4545	6410
5	7576	12640	9434	943	3559	1799	3300	4525
6	2257	10120	17640	459	1131	1712	1140	2985
7	2695	4587	20000	671	1642	2793	671	4464
8	10000	8475	20000	578	2304	3953	1098	4950
9	6667	11170	8929	641	2793	3215	775	5714
10	8621	9259	12630	120	16420	1969	917	2375
Overall PF	5920	8400	15300	406	3540	1750	1560	3370

Phase II
Protection Factor of Suit with Biomarine Rebreather (CCBA)

Subject No.: 5
Mask No.: 5
Rebreather No.: P191
Suit No.: L1

EXERCISE	TRIAL							
	1	2	3	4	5	6	7	8
1	10750	20000	3906	3636	16780	637	3115	5882
2	16230	9804	1543	2119	6452	532	1567	2217
3	20000	5405	2558	2398	18550	1389	1976	1938
4	4717	1065	848	758	2353	885	662	625
5	1328	329	431	990	602	394	405	467
6	1359	208	314	373	242	204	141	280
7	1961	238	358	231	276	208	182	380
8	2132	292	459	202	297	214	156	351
9	2212	227	358	233	229	227	258	264
10	2183	217	347	236	205	237	144	200
Overall PF	2640	388	537	417	440	324	284	440